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(54) Title of invention: COIL EXCITATION CIRCUIT OF AN ELECTROMAGNETIC CONTACTOR

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## SPECIFICATION

1. **Title of the invention:** **Coil excitation circuit of an electromagnetic (or solenoid) contactor**

2. **Patent Claims**

According to Client's instruction, the Patent Claims were not translated.

3. **Detailed explanation of the invention**

**Area of application of the invention**

This invention relates to an electromagnetic driver that uses a switching element and, especially, to an electromagnetic driving circuit suitable for an electromagnetic contactor that can be operated at two different voltages.

**Background of the invention**

As disclosed in Laid-Open Patent S55-103684, for example, a conventional electromagnetic driver using a switching element that generates a drive-starting pulse of set width by first adding the integral of the drive control signal of set width to a voltage frequency conversion circuit and thereafter generates a circuit control pulse, the width of which decreases in sequence while the drive control signal is being added.

Also, as shown in Utility Model S59-38016, a coil is connected to the full wave rectifier circuit via a thyristor, an oscillation circuit is formed by using a transistor, PUT, etc., a circuit is composed to connect the thyristor by the output of the said oscillation circuit, and the charging circuit of the capacitor of the oscillation circuit is switched to allow a large current flow as the starting current from switch-on to a set time, and a small current as the retention current after the set time. However, in the said conventional example, although compensation for the change in source voltage is disclosed, the idea of common use of the coil for two different voltages, such as 100 V or 200 V and 200 V or 400 V is not disclosed. Furthermore, a composition for common use of the coil for two voltages, in which a pulsed voltage is added to the coil and the pulse width of the said voltage is changed according to the input voltage, was being studied before arrival at this

invention and a patent was applied for under Application No. S59-260695. However, in this application, the pulse width and the frequency generated for a given input voltage are constant. Therefore, to apply 200 V and 400 V as input voltage to the coil for 100 V, the electric consumption of switch-on increases if the pulse width is set too large to reduce the switch-on time and the coil can burn out or the core can wear due to excess current. When the connection time is decreased in order to prevent such problems, the switch-on time increases.

#### **Objective of the invention**

This invention offers an electromagnetic driver that uses the same coil for a wide range of voltages, such as AC 100 V-250 V.

#### **Outline of the invention**

[This paragraph on Japanese page 78 is a repeat of Claim 1, not translated according to client's request. - Translator]

According to a preferred embodiment, the said switch-on signal generating means is the 1st oscillation circuit that generates a pulse series, the ON-duty [sic] of which decreases gradually, based on the output of the said integration circuit; the said retention signal generating means is the second oscillation circuit that generates a constant frequency, and generates a pulse series, the pulse width which changes according to the level of output voltage of the said integration circuit.

According to another preferred embodiment, the said switch-on signal generating means is the 1st oscillation circuit that generates a pulse series, the ON-duty of which decreases gradually according to the output of the said integration circuit, and the said retention signal generation circuit is the said delay circuit.

#### **Practical Examples**

Practical examples of this invention are explained below. The first practical example is explained with the aid of Figures 1-6.

Figure 1 is a block diagram of the circuit of this practical example. In the figure, 1 is the input source, 2 is a rectifier circuit, 3 is the source of control circuit 4, 5 is a transistor, i.e., a

switching element, 6 is an electromagnetic coil and 7 is a free-wheeling diode. Input source 1 in this example is a 50 Hz or 60 Hz commercial source.

Figure 2 is a block diagram of drive control circuit 4. In this example, the circuit comprises voltage detection circuit 42, signal delay circuit 43, input voltage integration circuit 41, sawtooth-wave generation circuit 44, comparison circuit 46, coil retention drive circuit 45 and output switching circuit 47.

Figure 3 shows the specific circuit of this example and the main waveforms are shown in Figures 4-6. Incidentally, as an example, Figures 4 and 5 show the waveforms for a 100 V and 200 V input source, respectively. In this example, rectifier circuit 2 is composed of diode bridge  $D_1$  and the AC input side of bridge  $D_1$  is connected to input source 1 and the minus side of the DC output side is grounded (hereafter, GND) and the plus side is connected to source circuit 3 and electromagnetic coil 6 and input terminals of integration circuit 41, voltage detection circuit 42 and signal delay circuit 43 and it generates waveform a of Figures 4 and 5.

Source circuit 3 is a known stabilizing source circuit and it stabilizes the output voltage of rectifier circuit 2 and supplies it to voltage detection circuit 42, signal delay circuit 43, sawtooth wave generating circuit 44 and coil retention drive circuit 45 as their source voltage  $V_{cc}$ , respectively.

Next, the composition and functions of these circuits are explained.

Voltage detection circuit 42 is composed of resistor  $R_{21}$ , one end of which is connected to the plus side input of comparator  $Q_{21}$  and the other end is connected to the output of rectifier circuit 2; smoothing capacitor  $C_{21}$  connected between the plus side input of comparator  $Q_{21}$  and GND; resistor  $R_{22}$  that is connected parallel to smoothing capacitor  $C_{21}$  and discharges an accumulated charge of capacitor  $C_{21}$ ; resistor  $R_{23}$ , one end of which is connected to the minus-side input of comparator  $Q_{21}$ , Zener diode  $ZD_{21}$ , the cathode of which is connected to the minus side of comparator  $Q_{21}$  and the anode is connected to the GND; and buffers  $Q_{22}$ ,  $Q_{23}$  which are connected to the output terminal of comparator  $Q_{21}$  and have an open collector output respectively, and the said outputs are connected to the input side of capacitor  $C_{11}$  of integration circuit 41 and the input side of capacitor  $C_{31}$  of signal delay circuit 43.

Voltage detection circuit 42 evaluates the level of the voltage generated in rectifier circuit 2 and it connects the open collector output of buffers  $Q_{22}$ ,  $Q_{23}$  when the voltage is insufficient for attraction of electromagnet 6 and it short circuits both ends of capacitor  $C_{11}$  of integration circuit 41 and capacitor  $C_{31}$  of signal delay circuit 43 to put the integration circuit and the signal delay circuit 43 in a waiting state.

When the output voltage of rectifier circuit 2 is sufficient to attract electromagnet 6, the open collector outputs of buffers  $Q_{22}$ ,  $Q_{23}$  are not connected.

Thereby, capacitor  $C_{11}$  of integration circuit 41 and capacitor  $C_{31}$  of signal delay circuit 43 are added to output b of Figures 4 and 5 and they start charging for the operation of integration circuit 41 and signal delay circuit 43. Integration circuit 41 is composed of resistor  $R_{11}$ , one end of which is connected to the plus side output of rectifier circuit 2 and the other end is connected to GND via capacitor  $C_{11}$  and resistor  $R_{12}$ , which is connected parallel to capacitor  $C_{11}$ . It commences integration of a full rectifier waveform of rectifier circuit 2 according to the open collector output of buffer  $Q_{22}$  and generates output d of Figures 4 and 5.

In this example, the switch-on signal generation means is 1st oscillation circuit 40, composed of sawtooth-wave generation circuit 44 and comparison circuit 46. Sawtooth-wave generation circuit 44 is a known circuit and it produces sawtooth waveform d of Figures 4 and 5 by applying positive feedback to amplifier  $Q_{41}$ . This sawtooth wave has a frequency of approximately 300 Hz-500 Hz. In the sawtooth-wave generation circuit 44,  $R_{41}$ - $R_{45}$  are resistors,  $C_{41}$  is a capacitor and  $D_{41}$ ,  $D_{42}$  are diodes.

Comparison circuit 46 is composed of comparator  $Q_{61}$ . The output of sawtooth-wave generation circuit 44 is connected to the plus side input of comparator  $Q_{61}$  and output of integration circuit 41 is connected to the minus side input for voltage comparison of these waveforms, and it produces pulse series f of Figures 4 and 5.

As shown above, the pulse width of the pulse series of 1st oscillation circuit (f of Figures 4 and 5) changes with the output voltage of integration circuit 41. The pulse width is wide when the output of the integration circuit 41 is started and it is narrow when the output of rectifier circuit

2 is near the peak of the full rectified waveform, as the output voltage of integration circuit 41 increases. Furthermore, the pulse width is wide when it is near the valley.

In this example, the retention signal generation means is the 2nd oscillation circuit 45, which is composed of a sawtooth-wave oscillation circuit that is the positively fed-back amplifier  $Q_{51}$  and comparator  $Q_{52}$ . The 2nd oscillation circuit 45 compares outputs of the sawtooth-wave generation circuit and integration circuit 41 by the use of comparator  $Q_{52}$ , and it generates a pulse series of narrow pulse width when the output voltage of integration circuit 41 is high and a pulse series of wide pulse width when the output voltage is low (g of Figures 4 and 5).

In the 2nd oscillation circuit 45,  $C_{51}$  is a capacitor and  $R_{51}$ - $R_{56}$  are resistors. Incidentally, the pulse series of the output of 2nd oscillation circuit 45 is used to set the coil retention circuit so that the constants of the elements of oscillation circuit 45 are such that the ON-duty of the 2nd oscillation circuit is smaller than that of the output pulse series of 1st oscillation circuit 40. In this example, the frequency is longer than that of pulse series f, but the frequency can be raised to approximately 20 kHz. Signal delay circuit 43 is composed of a first time-constant circuit consisting of resistor  $R_{31}$  and capacitor  $C_{31}$ , protection resistors  $R_{33}$  and Zener diode  $ZD_{31}$ , protection resistor  $R_{33}$  for Zener diode  $ZD_{31}$ , pull-up [sic] resistor  $R_{34}$  for the output of comparators  $Q_{31}$ , comparators  $Q_{31}$ ,  $Q_{32}$ , pull-up resistor  $R_{36}$  for the output of compensator  $Q_{32}$ , and a 2nd time-constant circuit composed of resistor  $R_{35}$  and capacitor  $C_{32}$ .

One end of resistor  $R_{31}$  of the first time constant circuit is connected to the plus side output of rectifier circuit 2 and the other end is connected to one end of capacitor  $C_{31}$ . The other end of capacitor  $C_{31}$  is connected to GND. In addition, resistor  $R_{32}$ , for discharging of the residual charge, is connected parallel to capacitor  $C_{31}$ .

The connection point between resistor  $R_{31}$  and capacitor  $C_{31}$  is connected to the open collector output of buffer  $Q_{23}$  of voltage detection circuit 42 and to the plus side input of comparator  $Q_{31}$ . The anode of Zener diode  $ZD_{31}$  is connected to GND and its cathode is connected to Vcc via resistor  $R_{32}$ . The minus side input of comparator  $Q_{31}$  is connected to the cathode of Zener diode  $ZD_{31}$  and kept at a constant voltage. Comparator  $Q_{31}$  has an open collector output and its output is connected to Vcc via pull-up resistor  $R_{34}$  and to GND via resistor  $R_{35}$  and capacitor  $C_{32}$ .

The minus side input of comparator  $Q_{32}$  is connected to the cathode of Zener diode  $ZD_{31}$  and the plus side input is connected to the connection point between resistor  $R_{35}$  and capacitor  $C_{32}$ . Comparator  $Q_{32}$  has an open collector output and the output is connected to  $V_{cc}$  via pull-up resistor  $R_{36}$  and to output switching circuit 47. Thereby, the open collector output of buffer  $Q_{23}$  becomes unconnected when the output of rectifier current 2 is sufficient to attract electromagnet 6 and the output of rectifier circuit 2 is charged in capacitor  $C_{31}$  and the voltage of capacitor  $C_{31}$  increases. When the voltage exceeds the standard voltage of Zener diode  $ZD_{31}$ , the open collector output of comparator  $Q_{31}$  becomes not connected. Thereby, capacitor  $C_{32}$  is charged via resistor  $R_{35}$  and its voltage increases. When the voltage exceeds the standard voltage of Zener diode  $ZD_{31}$ , the open collector output of comparator  $Q_{32}$  becomes disconnected and the output is supplied to output switching circuit 47.

As shown above, signal delay circuit 43 generates output c of Figures 4 and 5 after the open collector output of buffer  $Q_{23}$  becomes disconnected and after delay time  $t_2$ , due to the 1st and 2nd time constant circuits. This delay time is set as switch-on time  $t_0$  of the coil plus a small time delay  $t_1$ .

The output switching circuit is composed of inverter  $Q_{73}$ , AND gates  $Q_{71}$ ,  $Q_{72}$  and the OR circuit composed of diode  $D_{71}$  and  $D_{72}$ . AND gate  $Q_{71}$  is a two-input AND gate and one of its inputs is the output of 1st oscillation circuit 40 and the other input is the output of signal delay circuit 43 via inverter  $Q_{72}$ . Thereby the output is generated by AND gate  $Q_{71}$  when the output of signal delay circuit 43 is at level L and the output of the 1st oscillation circuit is at level H. AND gate  $Q_{72}$  is a two-input AND gate and one of its inputs is the output of 2nd oscillation circuit 45 and the other is the output of signal delay circuit 43. Thereby, AND gate  $Q_{72}$  generates an output when the input of signal delay circuit 43 is at level H, and the output of the 2nd oscillation circuit is at level H.

The outputs of AND gates  $Q_{71}$  and  $Q_{72}$  are connected respectively to the base of transistor 5 via the OR circuit composed of diodes  $D_{71}$ ,  $D_{72}$ . Since signal switching circuit 47 is composed as above, the output of 1st oscillation circuit 40 is supplied to the base of transistor 5 when the output of the signal delay circuit is at level L and the output of signal delay circuit 43 is supplied to the base of transistor 5 when the output of signal delay circuit 43 is at level H.



In Figures 4 and 5, i indicates the stroke of the movable core (not shown), which is attracted by coil 6. The movable core is provided with a set gap G as against fixed core (not shown) and the gap becomes zero when it is attracted by the fixed core due to excitation of coil 6 and after switch-on time  $t_0$ .

Figure 6 shows the output of voltage detection circuit 42, switching circuit 47 versus the current waveform of coil 6 versus the stroke of moveable core relationship. In the figure, b, c and i are the output of voltage detection circuit 42, the output of switching current 47 and the stroke of the moveable core, respectively, and the codes assigned there are the same as in Figures 4 and 5. In Figure 6, j and k are the current waveforms of coil 6 for 100 V and 200 V of this example, respectively. With this example, the coil current can be started up sharply as j and k of Figure 6, to supply the pulse series with gradually decreasing ON duty and can be held at a near constant later in the time of switch-on so that attraction of an electromagnet can be performed in a short time and shock due to excess current in the later time of switch-on can be suppressed.

As shown by l in Figure 6, large current can be made to flow at an early time of switch-on and it can be reduced gradually thereafter by a properly set impedance and the pulse width of the coil.

Next, when the coil rated for 100 V is used in this example, as shown by f, g and h of Figures 4 and 5, the pulse width for 200 V is smaller than that for 100 V when connections to 100 V and 200 V are compared. With this example, electricity supplied to the coil can be held near constant, even if the input voltage varies greatly and, at the same time, the pulse width can be controlled regardless of the frequency of input voltage.

A second practical example of this invention is explained with the aid of Figures 7 and 8.

Figure 7 is a block diagram of a major portion of this example and Figure 8 is a waveform chart of various parts of this example. In the example, electromagnet drive circuit 14 is composed of integration circuit 41, voltage detection circuit 42, delay circuit 43, 1st oscillation circuit 52, 2nd oscillation circuit 45 and switching circuit 47. In this example, 1st oscillation circuit 52, which is a switch-on signal generation means, is composed of voltage frequency conversion circuit

49 (hereafter, V/F conversion circuit) that oscillates at a frequency based on the output of 1st integration circuit 41 and an inverter circuit 50 that is connected to the output of V/F conversion circuit 49. In this example, when the input source is switched on and the output voltage of rectifier circuit 2 is sufficient to attract coil 6, voltage detection circuit 42 is operating and output b of Figure 8 is generated and the operations of integration circuit 41 and delay circuit 43 are started. When integration circuit 41 is operating and output d of Figure 8 is generated, V/F conversion circuit 49 generates a pulse series of constant pulse width at a frequency that is nearly proportional to the output of integration circuit 41. The pulse interval of this pulse series is wide and narrow in the start and the end of switch-on, as shown in Figure 8, so that sufficient drive force cannot be produced at the start of switch-on if it is left as is. Therefore, the waveform is inverted by inverter 50 to generate a pulse series with wide and narrow pulse width at the start and end of switch-on as the output of 1st oscillation circuit 52, as shown in k in Figure 8. The 2nd oscillation circuit 45, which is a retention signal generation means, generates a pulse series (g of Figure 8) with a constant frequency and a pulse width that changes with the output of integration circuit 41, similarly to the first practical example.

Switching circuit 47 switches the signal supplied to switching element 5 from the output of 1st oscillation circuit 52 to the output of 2nd oscillation circuit 45 by the use of the output (c of Figure 8) that is generated after a set time from operation start of the delay circuit 43, similarly to the first practical example. Thereby, pulse series l of Figure 8 is supplied to switching element 5. Also, in this example, the coil current can be made almost constant as f in Figure 8, in the later time of switch-on, so that the shock due to the excess amount can be suppressed.

A third practical example of this invention is explained below with the aid of Figures 9-11. In this example, bidirectional thyristor 16 is used as the switching element.

As shown in Figure 9, in this example, coil 6 is connected to the DC output side of diode bridge  $D_2$  that is connected to input source 1. The AC input side of diode bridge  $D_2$  is connected to input source 1 via bidirectional thyristor 16 and the current supplied to coil 6 is controlled through controlling the AC input of bidirectional thyristor 16. As shown in Figure 10, in this example, electromagnet drive circuit 20 is composed of source circuit 3, voltage detection circuit 42, integration circuit 41, 1st oscillation circuit 40, composed of sawtooth-wave generation circuit 44 and comparison circuit 46, switching circuit 57, delay circuit 43, voltage discrimination circuit

58 and gate control circuits 59 and 60. Source circuit 3, voltage detection circuit 42, delay circuit 43 and 1st oscillation circuit 40 are the same as in the first practical example. In this example, the switch-on signal generation means is the 1st oscillation circuit 40 and the retention signal generation means is delay circuit 43.

Switching circuit 57 is composed of two-input AND gate  $Q_{71}$ , light-emitting element  $LD_{71}$  of photo coupler  $PC_1$  connected to the output terminal of AND gate  $Q_{71}$  via resistor  $R_{71}$  and inverter  $Q_{73}$ , which is connected to one input of AND gate  $Q_{71}$ . Two-input AND gate  $Q_{71}$ , one input terminal of which is connected to the output terminal of 1st oscillation circuit 40 and the other input terminal of 1st oscillation circuit 40 and the other input terminal is connected to the output terminal of delay circuit 43 via inverter  $Q_{73}$ . Thereby, a pulse series corresponding to the output of 1st oscillation circuit 40 is supplied to light-emitting element  $LD_{71}$  as the switch-on signal, while the output of delay circuit 43 is at level L, and then supplied to gate-control circuit 59 via photo coupler  $PC_1$ . When the output of the delay circuit is at level H, the output of AND gate  $Q_{71}$  is at level L and this state is transmitted to gate control circuit 59 as a retention signal via photo coupler  $PC_1$ . That is, in this example, delay circuit 43 also functions as the retention signal generation means.

Gate control circuit 59 is composed of diode bridge  $D_{91}$ , Zener diode  $ZD_{91}$ , photo transistor  $PT_{91}$ , which is the light-receiving element of photo coupler  $PC_1$ , uni-junction [sic] transistor  $UT_{91}$ , thyristor  $TA_{91}$ , diodes  $D_{92}$ ,  $D_{93}$ , resistors  $R_{91}$ - $R_{97}$  and capacitor  $C_{91}$ . Diode bridge  $D_{91}$  is connected to input source 1 via resistor  $R_{91}$  and generates a DC output, and Zener diode  $ZD_{91}$ , connected to the DC output side of diode bridge  $D_{91}$  via resistor  $R_{92}$ , supplies a constant voltage to subsequent circuits that are connected parallel between its cathode and anode.

The signal from switching circuit 57, electrically insulated, is transmitted to light-receiving element  $PT_{91}$  of photo coupler  $PC_1$  and uni-junction transistor  $UT_{91}$  sends a signal to the gate of thyristor  $TA_{91}$  based on such signal; the pulse from the connection and non-connection of said thyristor  $TA_{91}$  is supplied to the gate of the thyristor, which is a switching element, via resistor  $R_{96}$ .

When the output of delay circuit 43 is at level L, switching circuit 57 supplies a pulse series generated by 1st oscillation circuit 40 to the gate control circuit via photo coupler  $PC_1$  and, when the output of delay circuit 43 is at level H, after a set time, the retention signal is transmitted via

photo coupler PC1 so that thyristor 16 connects intermittently, based on the pulse series of the 1st oscillation circuit, as long as the output of delay circuit 43 is at level L, and it becomes disconnected when the output of delay circuit 43 is at level H. Voltage discrimination circuit 58 is composed of Zener diode  $ZD_{81}$  that generates standard voltage, comparator  $Q_{81}$ , light-emitting element  $LD_{81}$  of photo coupler PC2, resistors  $R_{81}$ - $R_{84}$  and capacitor  $C_{81}$ . Comparator  $Q_{81}$  compares the output voltage of rectifier circuit 2 with the standard voltage of Zener diode  $ZD_{81}$  and, when the output voltage is lower than the standard value, it lights up light-emitting element  $LD_{81}$ . Thereby, light-emitting element  $LD_{81}$  lights up for 100 V and stops light emission at 200 V, when two voltages, for example, 100 V and 200 V, are used for the electromagnet drive circuit of this example.

Gate control circuit 60 is composed of bidirectional thyristor  $PT_{61}$  which is the light-receiving element of photo coupler PC2 and resistor  $R_{61}$ . Photothyristor  $PT_{61}$  and resistor  $R_{61}$  are connected in series and the main electrode of photothyristor  $PT_{61}$ , not connected to resistor  $R_{61}$ , is connected to the gate of thyristor 18 and resistor  $R_{61}$  is connected to main electrode  $T_2$  of bidirectional thyristor 18. Thereby, photothyristor  $PT_{61}$  is connected when light-emitting element  $D_{61}$  of photo coupler PC2 emits light and bidirectional thyristor 18, too, is connected. When light-emitting element  $LD_{61}$  does not emit light, photothyristor  $PT_{61}$  and bidirectional thyristor 18 are disconnected. In this example, coil b is connected to the DC output side of diode bridge  $D_2$  and diode bridge  $D_2$  is connected to input source 1 via bidirectional thyristor 16. In addition, the series circuit of resistor  $R_1$  and capacitor  $C_1$  and the series circuit of resistor  $R_2$ , capacitor  $C_2$  and bidirectional thyristor 18 are connected parallel to bidirectional thyristor 16. Thereby, in the beginning time of switch-on, the voltage pulse series of integration circuit 41, the pulse width of which decreases gradually with increase of output voltage of integration circuit 41, is added to coil 6, based on the pulse series generated by 1st oscillation circuit 40. When the output of delay circuit 43 is at level H and switching circuit 57 operates (in retention condition), bidirectional thyristor 16 is disconnected so that voltage from input source 1 is added via impedance of the series connection of resistor and capacitor.

When the voltage of input source 1 is low among the 2 voltages (e.g., it is 100 V), a circuit composed of a series circuit of resistor  $R_1$  and capacitor  $C_1$  and a series circuit of resistor  $R_2$  and capacitor  $C_2$ , which are connected parallel, is inserted on the AC input side of diode bridge  $D_2$  in the retention state. The current in coil 6 is thus controlled. When the voltage of input source 1 is

the higher of the 2 voltages (e.g. it is 200 V), bidirectional thyristor 18 is disconnected so that the series circuit of resistor  $R_1$  and capacitor  $C_1$  is inserted on the AC input side of the diode bridge  $D_2$ , in the retention state, in order to control the current in coil 6. In this example, resistors  $R_1$ ,  $R_2$  are set to approximately 60-100  $\Omega$  and capacitors  $C_1$ ,  $C_2$  are set to 0.5  $\mu\text{F}$  - a few  $\mu\text{F}$ .

Figure 11 shows the major waveforms of this example. In Figure 11, e is the output of rectifier circuit 2, b is the output of voltage detection circuit 42 and c is the output of delay circuit 43. When the source is switched ON and the output of voltage detection circuit 42 starts up, the output of delay circuit 43 starts up after a set delay time,  $t_2$ . A signal of 1st oscillation circuit 40 is supplied to gate control circuit 59 via switching circuit 57 until the output of delay circuit 43 starts up and uni-junction transistor  $UT_{91}$  supplies a trigger pulse to the gate of thyristor  $TA_{91}$  in synch with such a signal. Thereby, thyristor  $TA_{91}$  repeats the connection/disconnection in timing e of Figure 11 and bidirectional thyristor 16, too, repeats connection/disconnection at the same timing. Therefore, the DC output of the diode bridge  $D_2$ , controlled by the bidirectional thyristor, has a small control angle during the early time of switch-on, as shown by f in Figure 11 and the control angle increases gradually thereafter. The current in coil 6 starts up sharply in the early time of switch-on, as shown by g of Figure 11 and becomes nearly constant in the later time of switch-on. When output c of delay circuit 43 starts up after delay time  $t_2$ , the output of the switching circuit becomes OFF [sic], thereby, uni-junction transistor  $UT_{91}$  of gate control circuit 59 stops oscillation, as shown by d in Figure 11, thyristor  $TA_{91}$  is disconnected, as shown by e in Figure 11, and bidirectional thyristor 16 is disconnected too. Therefore, the AC input side of diode bridge  $D_2$  is connected to input source 1 via the series circuit of the resistor and capacitor and the output of diode bridge  $D_2$  becomes as f in Figure 11. Under these conditions the current in coil 6 is the retention current of Figure 11 g. This is because start-up of the voltage is delayed due to the presence of an L-C series circuit and the impedance of the capacitor is much higher than that of the coil.

With this example, the gate current of the switching element can be supplied directly from input source 1 so that source circuit 3 can be reduced in size. Since the gate control circuit of the switching element is electrically insulated from the switching circuit, etc., an error in operation, due to line noise, etc., can be prevented.

#### **Effect of the invention**

This invention can produce an electromagnetic coil excitation circuit that can address a wide range of voltage, ranging from approximately  $\frac{1}{2}$  to twice as high by use of a single type of coil of the same voltage rating.

**4. Brief explanation of the figures**

Figure 1 is a block diagram of the 1st practical example of this invention, for a coil excitation circuit of the electromagnetic contactor.

Figure 2 is a block diagram of an electromagnet drive circuit of the first practical example.

Figure 3 is a circuit diagram showing a specific coil excitation circuit for the electromagnetic contactor of the 1st practical example.

Figures 4 and 5 are waveform charts showing, as an example, the major waveforms for 100 V and 200 V input voltage.

Figure 6 is a waveform chart showing the coil current versus the stroke of the moveable core relationship that corresponds to the input voltage of the 1st practical example.

Figure 7 is a block diagram of the coil excitation circuit for the electromagnetic contactor of the 2nd practical example.

Figure 8 is a major waveform chart of the 2nd practical example.

Figure 9 is a block diagram of the coil excitation circuit for the electromagnet of the 3rd practical example.

Figure 10 is a circuit chart of a specific coil excitation circuit of the 3rd practical example.

Figure 11 is a waveform chart of the 3rd practical example.

2 - rectifier circuit

4, 14, 20 - electromagnet drive circuit